tephritic trachyte, or to Lacroix's nephelite-micromonzonite. It is proposed to call this particular variety of rock, *tautirite*, from the valley in which it occurs.

On Tahiti, in the valley of Ururoa on the north coast, there is a variety of haüynophyre with microscopic haüynites, analysis, 13, which is chemically somewhat like the haüynophyres analyzed and described by Lacroix, and by Marshall. The microcrystalline groundmass consists of alkalic feldspar, augite and magnetite, with small phenocrysts of haüynite, augite and very few brown hornblendes. A similar haüynophyre occurs sparingly in the valley of Faurahi, on the southwest side of Tahiti. Its chemical analysis is no. 12. These rocks are scarce on Tahiti.

On Raiatea the heavy sheet of trachytic lava, which tops the ridge and spurs of the northern half of the island, varies somewhat in composition in different places. On the second spur west of Mount Tapioi it has numerous phenocrysts of feldspar, with fewer of mica and paramorphs of hornblende. The chemical analysis, no. 10, shows it is kohalaite, or oligoclase-trachyte. A non-porphyritic gray lava on Moorea is unusual in appearance for rocks of this region. Its chemical analysis, no. 9, shows it is latite, an aphanitic lava phase of monzonite. The corresponding monzonite occurs as a variety of the syenitic rocks in the core of the Tahitian volcano.

THE LAW CONTROLLING THE QUANTITY AND RATE OF REGENERATION

By Jacques Loeb

Rockefeller Institute for Medical Research, New York

Communicated, March 18, 1918

1. It is well known that isolated pieces of a plant or a lower animal may regenerate into a whole organism again. In order to replace the current vague speculations concerning this phenomenon by a scientific theory in the sense of the physicist, quantitative experiments are required. The writer has for the past two years made such experiments which have led to a remarkably simple law controlling the quantity of regeneration in an isolated piece of an organism. This law can be expressed as follows: The mass of tissue regenerated by an isolated piece of an organism is under equal conditions and in equal time in direct proportion to the mass of growth material contained in the sap (or blood) of the isolated piece. The experiments on which this law is based were carried out on an organism unusually favorable for investigations of this kind, namely, the plant *Bryophyllum calycinum* (known to many laymen as the Bermuda 'life plant'). When leaves of this plant are isolated from the stem they will regenerate shoots in some or many of their notches. If a piece of

stem is cut out from a plant it will form shoots from its two most apical buds. My experiments have yielded the result that the mass of shoots formed in the latter case is in direct proportion to the mass of a leaf attached to the stem; and to the mass of the isolated leaf in the former case. The data concerning regeneration in an isolated leaf have already been published[1] but will be repeated here to show the identity of the law in both cases.

2. When we cut out two sister leaves of *Bryophyllum*. *i.e.*, a pair of leaves taken from the same node of a plant, and keep them under the same condition of moisture, temperature, and light, the two sister leaves possessing equal mass will produce approximately equal masses of shoots in equal times, although the number of shoots produced by the two sister leaves may vary considerably (table 1).

TABLE 1

INFLUENCE OF MASS OF LEAVES UPON MASS OF SHOOTS REGENERATED BY LEAF

			WEIGHT OF LEAVES	NUMBER OF SHOOTS	WEIGHT OF SHOOTS	MILLIGRAMS OF SHOOTS PRODUCED PER GRAM OF LEAF
			grams		*grams*	
Experiment I.	Duration, 22 days. .	8 leaves	16.430	37	1.675	102
		8 sister leaves	16.476	40	1.682	102
Experiment II.	Duration, 29 days. .	9 leaves	12.022	24	1.436	119
		9 sister leaves	11.861	20	1.348	114
Experiment III.	Duration, 30 days. . .	12 leaves, intact	18.435	25	2.884	156
		12 sister leaves, each cut into 4 pieces	17.070	50	2.747	161

When we reduce the mass of one set of the sister leaves (by cutting away parts of the leaf), while that of the other set remains intact, both sets of leaves will produce in equal time and under equal conditions shoots whose masses are approximately proportional to the masses of the two sets of leaves (table 2).

From this it follows that equal masses of leaves produce equal masses of shoots, regardless of the number of shoots. Since chemical substances (water and solutes) are the only factors among those to be considered here which can vary in direct proportion with the mass of the leaves, it follows that the quantity of shoot formation in an isolated leaf is determined by the quantity of certain material contained in the sap of the leaf. This material is probably the usual material required for growth: water, and certain solutes, sugar, amino acids, salts, etc.

3. It was necessary to test the validity of this law for the regeneration of shoots in isolated stems. The facts just mentioned suggested the method required to yield rational quantitative results. This method consisted in the measurement of the influence of the mass of a leaf attached to a piece of stem upon the quantity of shoot formation in the latter. In order to obtain strictly comparable results, it was necessary again to compare the effect of sister leaves, since sister leaves alone are sufficiently alike to guarantee comparable results. The method of procedure was as follows. Stems of *Bryophyllum* containing three nodes and one pair of leaves in the third (most basal) node were split longitudinally into two halves, each half containing one leaf. One leaf remained intact, while the sister leaf attached to the other half of the stem was reduced in size by cutting away the greater part. Six whole stems

TABLE 2

INFLUENCE OF MASS OF LEAVES UPON MASS OF SHOOTS REGENERATED BY LEAF

		WEIGHT OF LEAVES	NUMBER OF SHOOTS	WEIGHT OF SHOOTS	MILLIGRAMS OF SHOOTS PRODUCED PER GRAM OF LEAF
		grams		*grams*	
Experiment I. Duration 37 days..........	5 leaves, with center cut out	7.610	11	0.755	99
	5 sister leaves, intact	13.800	9	1.405	101
Experiment II. Duration, 25 days.........	7 leaves, with center cut out	9.899	21	1.213	122
	7 sister leaves, intact	16.935	25	1.995	118
Experiment III. Duration, 32 days.........	9 leaves, with center cut out	10.522	22	2.292	218
	9 sister leaves, intact	17.852	30	3.430	192

were used for one experiment. After splitting, the halved stems were suspended in an aquarium with the apices of the leaves just dipping in water. Each half stem formed one new shoot from the apical bud and new roots at the base, but regeneration started earlier in the half stems with a whole leaf attached than in the half stems with a leaf reduced in size. After about five weeks the regenerated shoots were cut off and weighed. It was found that *the mass of the shoots regenerated in the two sets of halved stems was in exact proportion to the mass of the leaves attached to the stems* (table 3).

A similar law seems to hold for the root formation though this will have to be determined more definitely. The same law seems also to hold for other cases of regeneration of *Bryophyllum* not discussed in this note.

We can, therefore, state that the quantity of regeneration in an isolated piece of an organism is under equal conditions and in equal time directly pro-

portional to the mass of growth material circulating in the sap (or blood) of the piece and required for the synthetical processes giving rise to the regenerated tissues and organs. If we measure the rate of regeneration by the mass of material regenerated in a given time, the law expressed for the quantity holds also for the *rate* of regeneration and in this form the law becomes a special case of the law of chemical mass action.

4. This law does not throw any light upon two other features of regeneration, namely, first, why it is that as a rule only the apical bud of an isolated piece of stem grows out and none of the buds situated more basally in the stem; and second, why it is that the same bud which grows out when the piece of stem is cut out from the whole plant does not grow out as long as the piece is part of a whole (and normal) plant. The writer published not long ago a series of experiments[2] which suggest that the growing apex (as well as the

TABLE 3

INFLUENCE OF MASS OF LEAVES UPON MASS OF SHOOTS REGENERATED BY STEM

		WEIGHT OF LEAVES	WEIGHT OF 6 REGENERATED SHOOTS ON STEM	MILLIGRAMS OF SHOOTS REGENERATED PER GRAM OF LEAF
		grams	grams	
Experiment I. Duration, 37 days..........	6 whole leaves	19.030	2.808	147
	6 sister leaves, reduced in size	2.853	0.443	152
Experiment II. Duration, 34 days..........	6 whole leaves	18.490	3.586	192
	6 sister leaves, reduced in size	3.503	0.668	190

leaves) of a plant continually produce and send toward the base of the plant substances which *inhibit* the growth of dormant buds. When a piece of stem is cut out from a plant these inhibitory substances contained in the stem will continue to flow toward the base, with the result that the most apical buds will be the first to become comparatively free from these inhibitory substances and hence will be the first to grow out. As soon as this happens, the growing buds will produce and send toward the base inhibitory substances, with the result that none of the more basally situated buds of the piece of stem can grow out. In the normal plant the material serviceable for growth can only be utilized by the growing region at the apex (and the base of the plant); and when a piece is cut out from the plant the same material becomes available for the growth of those buds which are the first to be freed from the inhibitory material which they contained while forming parts of the whole plant. The further qualitative as well as quantitative experiments which the writer has carried out since the publication of his preliminary note support this hypothesis.

Summary.—By measuring the influence of the mass of a leaf attached to an isolated piece of stem upon the process of regeneration in the piece, it has been possible to prove that the quantity of regeneration is in equal time and under equal conditions in direct proportion to the mass of the leaf. Since nothing except substances produced and sent out by the leaf can vary in direct proportion to its mass, it follows that the quantity of regeneration in an isolated piece of an organism is under equal conditions determined by the mass of material necessary for growth circulating in the sap (or blood) of the piece. If we measure the rate of regeneration by the mass of material regenerated in a given time, the law of regeneration becomes a special case of the law of chemical mass action. That this mass action on a bud is only possible in a piece of stem after it is isolated, the writer explains on the assumption that the apex of an intact plant sends constantly inhibitory substances into the stem preventing the buds contained in the stem from growing and consuming the material required for growth. When a piece of stem is isolated, the supply of these inhibitory substances from the growing region ceases and the most apical bud being the first to become free from the inhibitory substance will then come under the influence of the acting masses of the substances in the sap and regeneration will occur. The mystifying phenomenon of an isolated piece restoring its lost organs thus turns out to be the result of two plain chemical factors: the law of mass action and the production and giving off of inhibitory substances in the growing regions of the organism.

[1] Loeb, J., *Science, New York*, **45**, 1917, (436); *Bot. Gaz., Chicago*, **65**, 1918, (150).

[2] Loeb, J., *Science, New York*, **46**, 1917, (547).